Geopositional Accuracy Validation of Orthorectified Landsat MSS Imagery

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Scope of Work

This report provides results of an independent assessment of the horizontal geopositional accuracy of Earth Satellite (EarthSat) Corporation's GeoCover™ orthorectified Landsat Multispectral Scanner (MSS) imagery. This imagery was purchased through NASA's Earth Science Enterprise (ESE) Scientific Data Purchase (SDP) program via NASA contract NAS13-98046.

Background

The technique used to validate the geopositional accuracy of EarthSat's MSS imagery required the use of validated Landsat Thematic Mapper (TM) imagery. The validated TM imagery used in this assessment was also purchased from EarthSat through the SDP. The geopositional accuracy of this TM imagery was independently validated by Earth Science Applications (ESA) Directorate personnel prior to this effort.

The TM sensor onboard Landsat 4 and Landsat 5 is a high-spatial-resolution (30-meter ground sample distance (GSD)), multispectral system with seven bands in the visible and infrared (IR) regions of the electromagnetic spectrum. EarthSat used a two-step process to orthorectify the TM imagery used in this assessment. The first step orthorectified TM scenes for which government-provided ground control points (GCPs) were available. The second step used the initially orthorectified scenes as control to tie the remaining raw imagery together using a single block adjustment. These orthorectified regions correspond to general land areas, or blocks, throughout the world. The result of this process is the block-orthorectified set of Landsat TM imagery that was delivered to NASA through the SDP. The SDP contract specification for horizontal geopositional accuracy of the TM dataset is a net root mean square error ($RMSE_{net}$) of 50 meters.

SSC ESA Directorate personnel then independently validated the orthorectified TM imagery for horizontal geometric accuracy. Additional validation-dedicated, government-provided ground control data was used to this end (i.e., the validation-dedicated GCPs were separate and independent of the GCPs used in the EarthSat orthorectification process). However, because of the limited number of additional government-provided GCPs within each scene, the validation assessment was performed by geographic block as opposed to individual scenes. Table 1 presents the results of the TM geolocational accuracy assessment including the x-component of the root mean square error ($RMSE_x$), the y-component of the root mean square error ($RMSE_y$), and the $RMSE_{net}$. Additional background and test procedures used in the TM validation effort may be found in the publicly available TM validation reports located on the ESA Web site at http://www.esa.ssc.nasa.gov/datapurchase/v_v/es/es_val_reports.asp.

The MSS sensor onboard Landsat 1 through Landsat 4 is also a high-spatial-resolution (57-meter GSD), multispectral system with four bands in the visible and near- IR regions of the electromagnetic spectrum. EarthSat orthorectified the MSS imagery used in this assessment using an "image mapping" method. This method orthorectified the individual MSS scenes to their corresponding orthorectified TM scenes. Unlike the TM orthorectification process, which yielded a block-orthorectified dataset, the result of the image mapping process was a set of MSS imagery where each scene was orthorectified individually.

Table 1. TM Horizontal Geometric Accuracy Results

Geographic Block	$RMSE_x$ (m)	$RMSE_y$ (m)	$RMSE_{net}$ (m)
Alaska	30.57	33.40	45.28
Balkans	23.17	21.53	31.62
Caribbean	19.17	19.87	27.61
Central America	19.44	15.32	24.75
Central Asia	18.45	27.53	33.14
Central North America	19.33	18.56	26.80
East Africa	20.88	18.97	28.21
Eastern North America	18.66	18.90	26.56
Europe	24.46	26.64	36.16
Middle East	32.84	29.12	43.89
North Africa	28.95	38.28	48.00
Northeast Asia	24.42	25.61	35.39
Northwest Asia	35.81	27.39	45.09
South Africa	17.86	19.22	26.24
Southeast Asia	24.38	26.45	35.97
Southern South America	1.58	2.40	2.87
Western North America	16.08	14.45	21.62

SSC ESA Directorate personnel validated the geopositional accuracy of the orthorectified MSS imagery by performing a relative assessment between the TM and MSS imagery. In other words, the geopositional accuracy of the MSS scenes was determined relative to their corresponding validated TM scenes. The TM images used in this investigation were the same images used in the original TM validation assessment. The rationale for this approach is explained in the following section.

Approach

To understand the MSS validation approach, it is useful to define the TM and MSS horizontal accuracy specifications. The geometric accuracy specified for Landsat TM imagery procured through the SDP is an $RMSE_{net}$ of ±50 meters as specified by NASA contract NAS13-98046 with Earth Satellite Corporation. Similarly, the geometric accuracy specification for Landsat MSS imagery procured through the SDP is an $RMSE_{net}$ of ±100 meters.

The coarser spatial resolution of the MSS orthorectified products did not permit the identification of the same ground control features used for the TM accuracy assessment. Thus, a direct absolute accuracy assessment using identifiable GCPs was not possible. Additionally, because EarthSat orthorectified the MSS imagery on a scene-by-scene basis using TM imagery as horizontal control, a scene-by-scene assessment approach for the MSS imagery was identified as more appropriate than the regional block assessment used in the TM validation. In addressing these two issues, it became clear that a relative geometric assessment between the previously validated TM imagery and the MSS imagery was the best available approach for this assessment.

To verify the accuracy of the MSS imagery, selected MSS scenes were compared to the corresponding verified/validated TM scene. In this analysis, it was assumed that if a particular TM scene was found to meet the ±50-meter $RMSE_{net}$ specification, that scene could serve as "truth" for verification of the corresponding MSS scene for the same area. The results of the SSC ESA Directorate independent TM validation are shown in Table 1. This table shows that all of the TM geographic blocks meet the ±50-meter horizontal accuracy specification and are viable control sources for the MSS geometric verification/validation effort. The locations of identifiable features in MSS scenes were compared to the locations of the same features within the TM scenes. Because the method for assessing the geometric accuracy of MSS imagery is relative to the previously validated TM imagery, it was determined that as long as the $RMSE_{net}$ of the MSS imagery was ≤50 meters, then the imagery would be within specification. If the imagery produced an $RMSE_{net}$ >50 meters, a worst-case scenario investigation into the TM and MSS imagery would ultimately determine the success or failure of the scene to meet the specification.

Dataset

The limited number of TM scenes having validation-dedicated, government-provided control data ultimately determined the size of the dataset that could be used in the Landsat MSS geopositional accuracy assessment. A total of 91 Landsat MSS scenes, each corresponding to validated Landsat TM scenes, were used in this assessment. Appendix A contains a map showing the location of the scenes used in relation to the entire globe.

Procedure

The relative horizontal geopositional accuracy assessment of MSS imagery began with the identification of MSS imagery that corresponded to validated TM imagery. Next, the data were analyzed using the GCP editor function available in ERDAS IMAGINE image processing software. For each scene, the Landsat MSS and corresponding TM images were opened in separate viewers. At this point both the MSS and TM images were inspected for clearly identifiable features. When specific landmarks, such as rock formations, roads, and waterways, were identifiable in both scenes, these landmarks were selected and geographically located. This action populated the X-Input and Y-Input fields in the software's GCP editor. The Universal Transverse Mercator (UTM) coordinates associated with each landmark in the MSS scene were compared to the UTM coordinates associated with each corresponding landmark in the TM scene.

After locating a minimum of 20 usable points within the MSS-TM scene pair, the analyst exported an American Standard Code for Information Interchange (ASCII) file that contained the Point IDs, input coordinates, and reference coordinates for each scene examined. These individual files provided the required input into the SSC ESA Directorate Visual Basic program written to compute relative geopositional accuracy. For each point, the Visual Basic program computed the X-differences and Y-differences, the squares of the X-differences and Y-differences, the $RMSE_x$ and $RMSE_y$, and the $RMSE_{net}$.

$$\mathrm{RMSE}_{\mathrm{X}} = \sqrt{\frac{\sum\left(X_{input} - X_{control}\right)^2}{n}}$$

$$\mathrm{RMSE}_{\mathrm{Y}} = \sqrt{\frac{\sum\left(Y_{input} - Y_{control}\right)^2}{n}}$$

$$\mathrm{RMSE}_{\mathrm{net}} = \sqrt{\left(RMSE_X\right)^2 + \left(RMSE_Y\right)^2}$$

where:
x_{input}, y_{input} are the coordinates of the MSS input points,
$x_{control}$, $y_{control}$ are the coordinates of the TM reference points,
n is the total number of usable control points

Limitations

Because the validated Landsat TM imagery is treated as a "truth" dataset for the MSS validation, it introduces limitations in the MSS validation approach. First, the same dataset is used in the EarthSat orthorectification process and the independent accuracy validation process, so the validation method is not truly independent. Second, any accuracy errors in the TM imagery can potentially have adverse affects on the absolute geometric accuracy of the validated MSS imagery. Appendix B provides a cartographic representation showing the locations of the TM scenes for each Landsat block used in validating the orthorectified MSS imagery. Additionally, each cartographic representation provides the resultant error vectors of all of the scenes from the NASA ESA Directorate's assessment of TM imagery. The resulting vector length represents the relative magnitude of error. The direction of the resulting vector represents the overall direction of the error. This cartographic output was derived from a government-provided vector-based program, "GeoCover Analysis."

The MSS validation approach was also dependent on the geographic distribution of the available MSS-TM scene pairs used in the assessment. This distribution is shown in Appendix A. This validation procedure assumes that the scenes selected represent a large enough sample of imagery to be extrapolated to the rest of the MSS imagery covering the globe.

The possibility exists for inherent analyst bias because of the variability in image interpretation and pattern recognition capabilities. Final selection of points reflects user subjectivity.

Results

In 87 percent of the scenes, the RMSEnet was ≤50 meters or the scenes yielded results such that the observed geolocational accuracy passed a worst-case scenario test (i.e., $TM\ RMSE_{net} + MSS\ RMSE_{net} \leq 100\ meters$). Four percent of the imagery was unable to be evaluated for different reasons, including extreme scene uniformity. The remaining 9 percent of the imagery failed to meet the specification in a worst-case scenario (i.e., $TM\ RMSE_{net} + MSS\ RMSE_{net} > 100\ meters$). Of this 9 percent, 4 images violated the RMSEnet worst-case scenario by <10 meters. Table 2 depicts a brief summary of the results. Table 3 depicts details on the scenes that failed the worst-case scenario.

Table 2. MSS Validation Pass/Fail Metrics

Pass/Fail Criteria	**Number of Scenes**	**Percentage of Scenes**
Passed	80	87%
Failed: Exceeded worst-case absolute $RMSE_{net}$	8	9%
Scenes unable to validate	4	4%
Total Scenes	92	

Table 3. Calculations for MSS Scenes that Failed the Worst-Case Scenario

Block	**TM Path**	**TM Row**	**MSS Path**	**MSS Row**	**TM $RMSE_{net}$ (m)**	**MSS $RMSE_{net}$ (m)**	**Worst-Case $RMSE_{net}$ (m)**
East Africa	176	55	189	55	28.21	110.45	138.66
East Africa	178	46	191	46	28.21	72.82	101.03
Eastern North America	22	39	23	39	26.56	75.62	102.18
Europe	198	23	213	23	36.16	71.08	107.24
North Africa	196	34	211	34	48.00	60.89	108.89
Southeast Asia	130	50	140	50	35.97	86.43	122.40
Southeast Asia	130	52	139	52	35.97	85.15	121.12
Southeast Asia	133	48	143	48	35.97	90.55	126.52

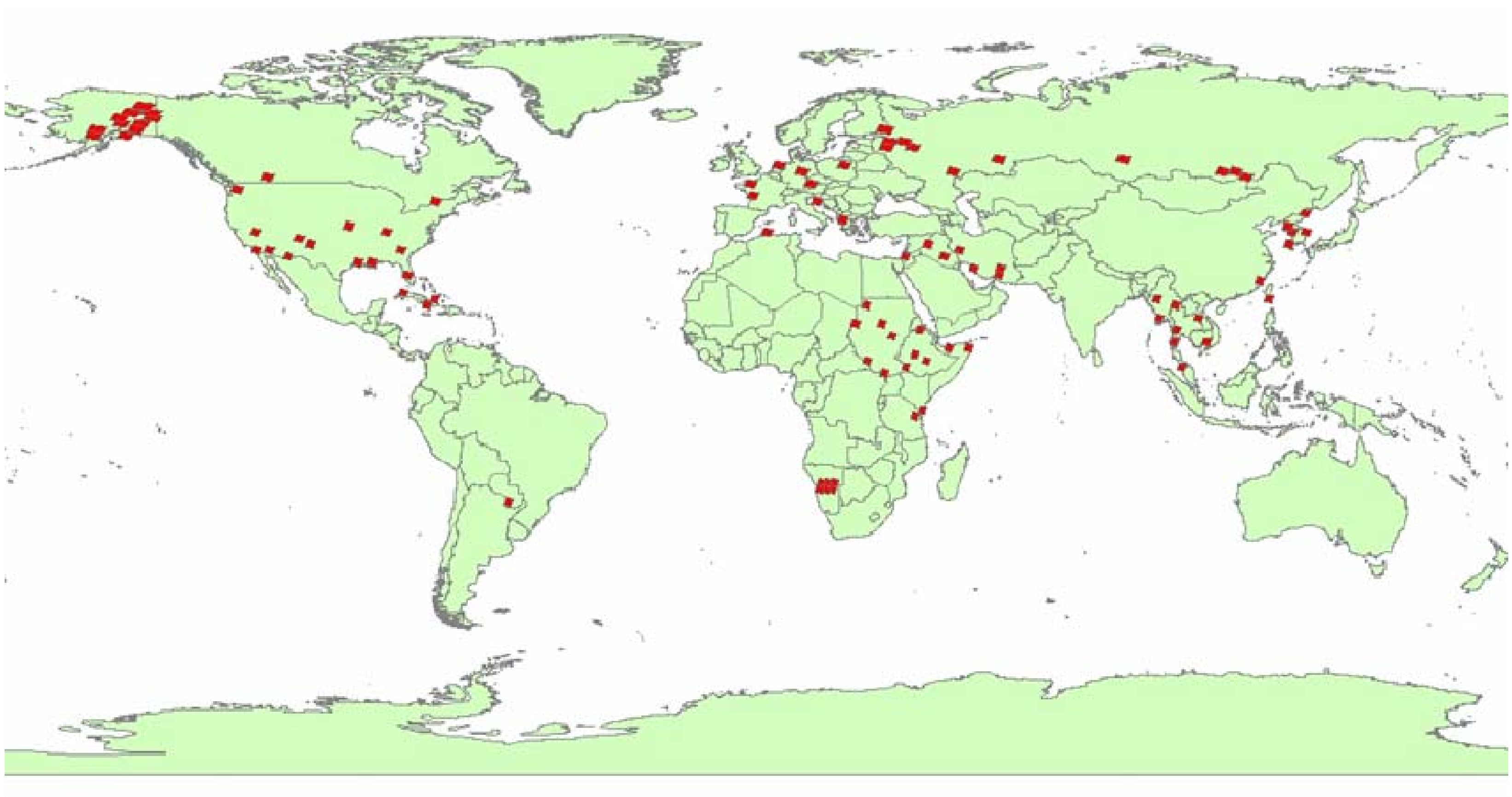
The data results for each individual scene are recorded in Appendix C. These results record the Path/Row of the Landsat MSS and TM imagery as well as the RMSEx, RMSEy, and the RMSEnet for each scene.

Conclusions

Given the limitations inherent in this analysis, it is evident that to a great extent the MSS imagery meets specifications. EarthSat has been notified of the few scenes that failed to meet the geolocational specifications or were unable to be validated. For various reasons, EarthSat was willing to accept the failures of the 8 scenes and the inability to validate the remaining 4 scenes for the purposes of this report. No further deliveries of validation data are expected at this time.

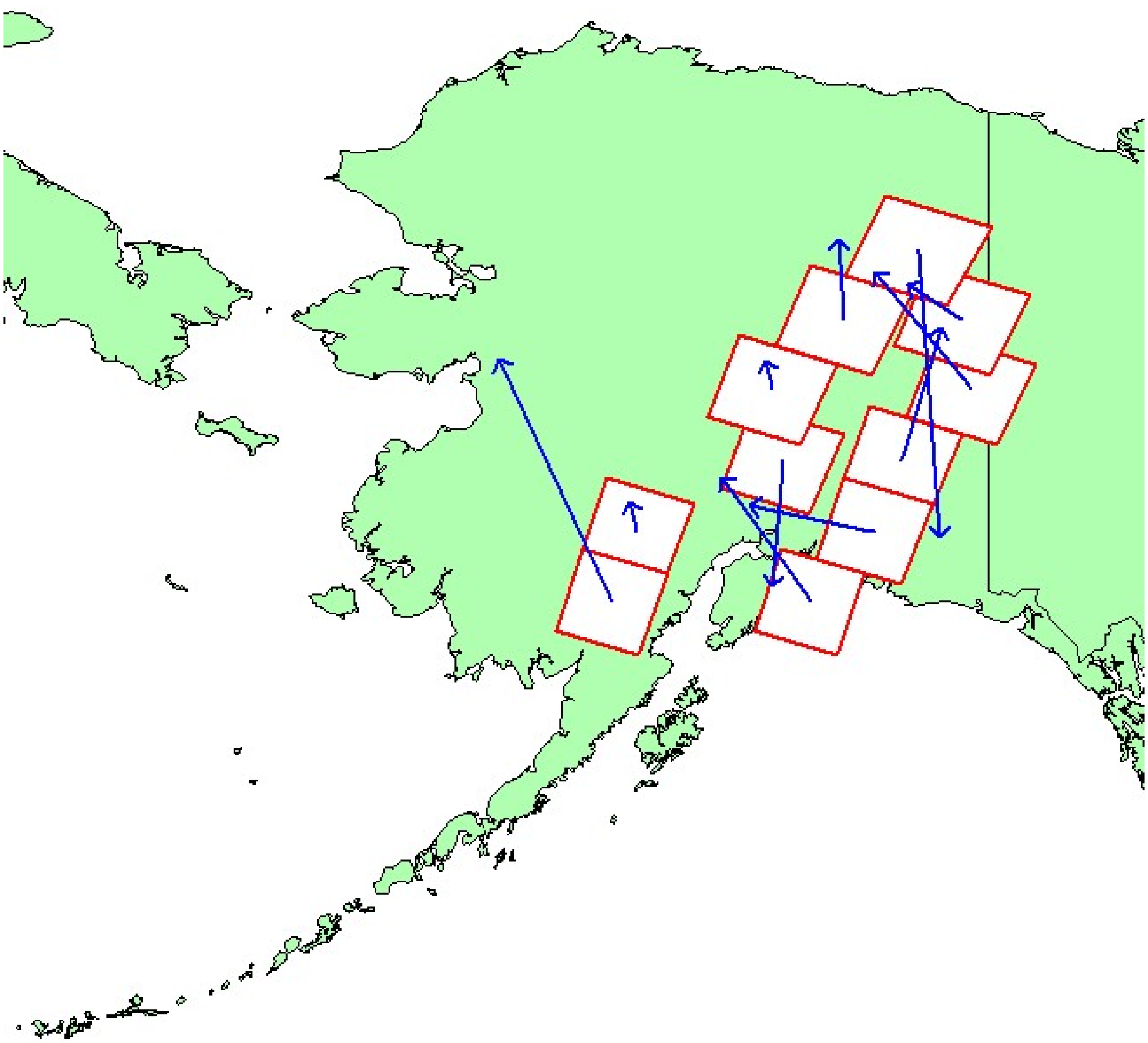
Appendix A

Validated Landsat MSS Scene Locations

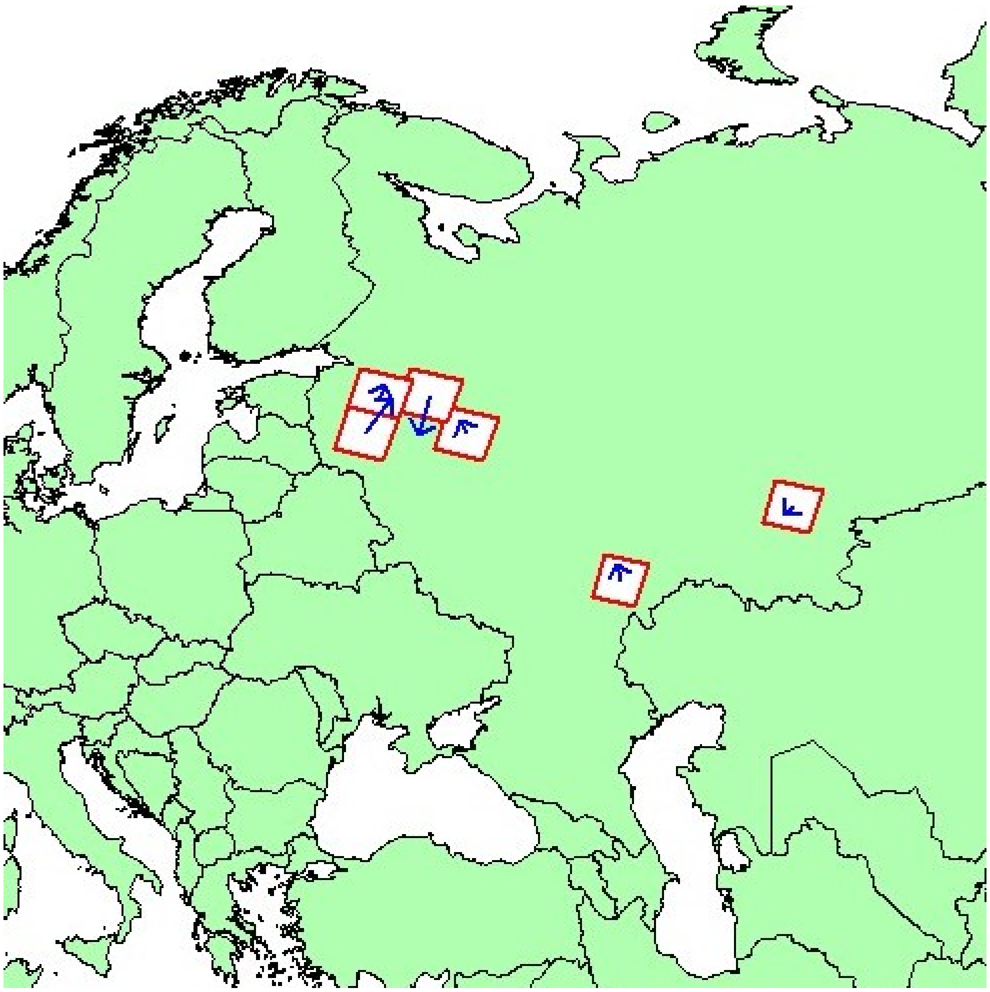


Appendix B

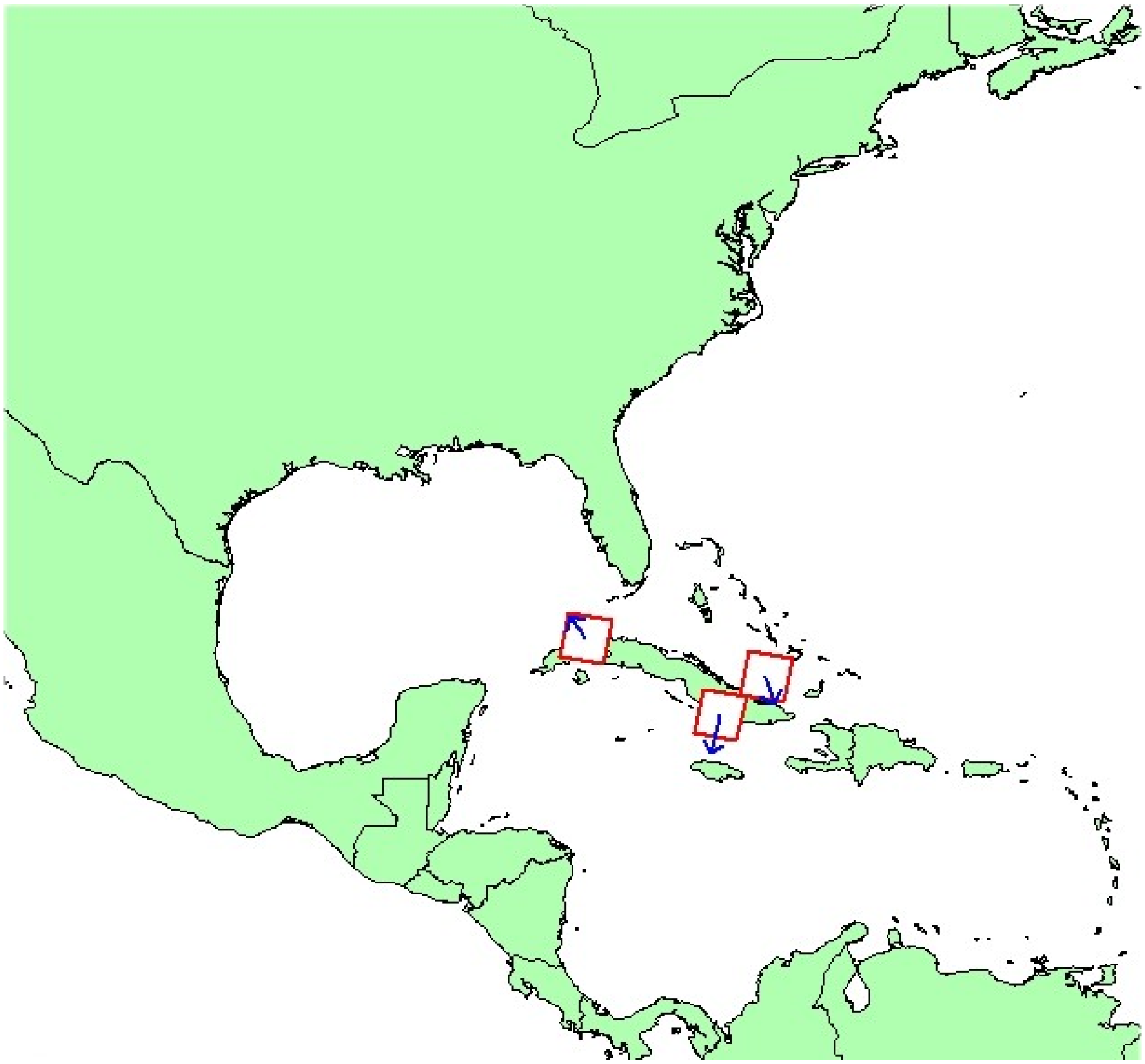
Landsat TM Scene Errors



Alaska Landsat TM Scene Errors

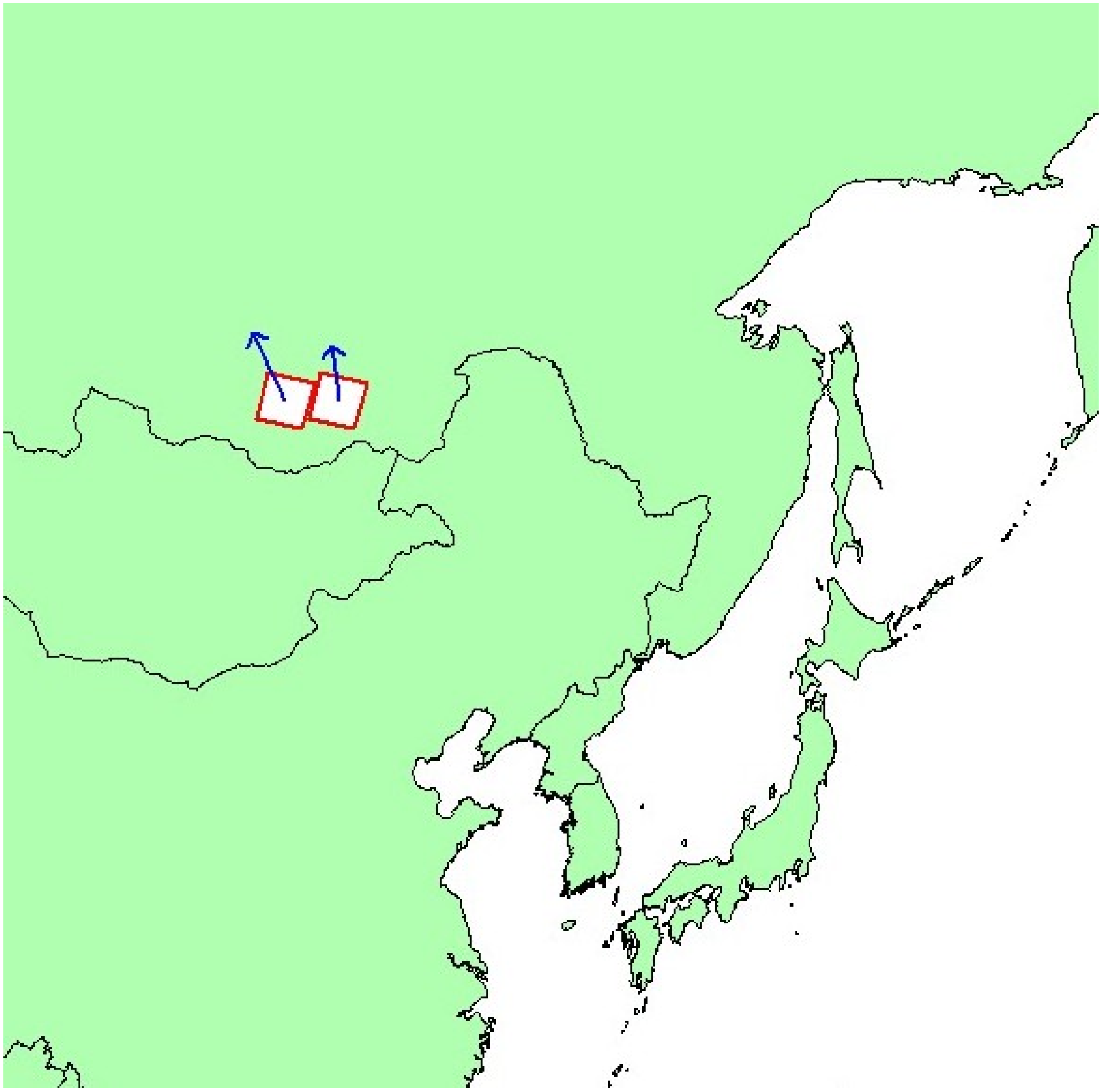


Balkans Landsat TM Scene Errors

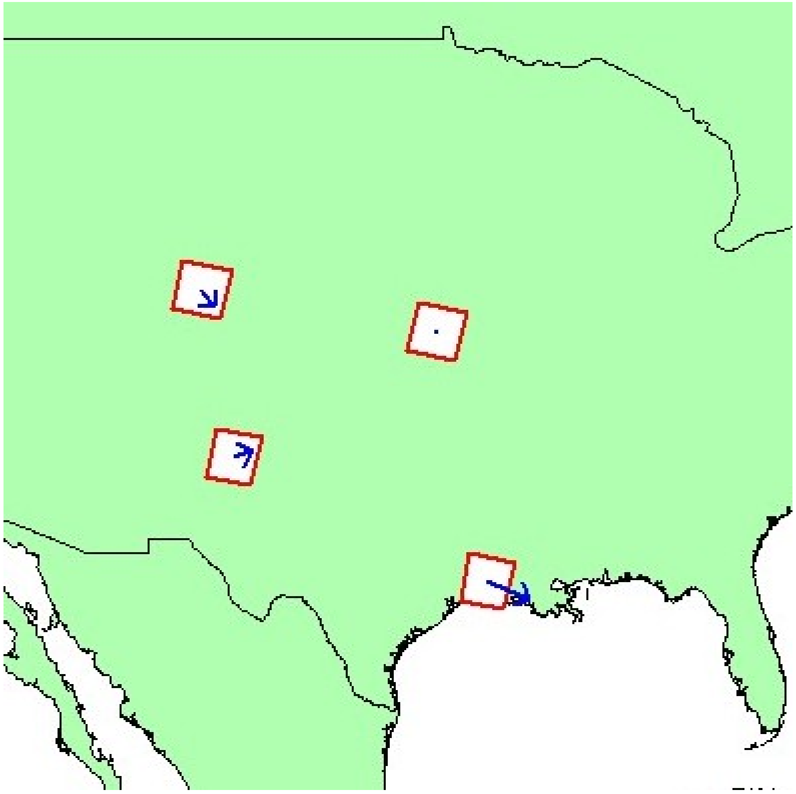


Caribbean Landsat TM Scene Errors

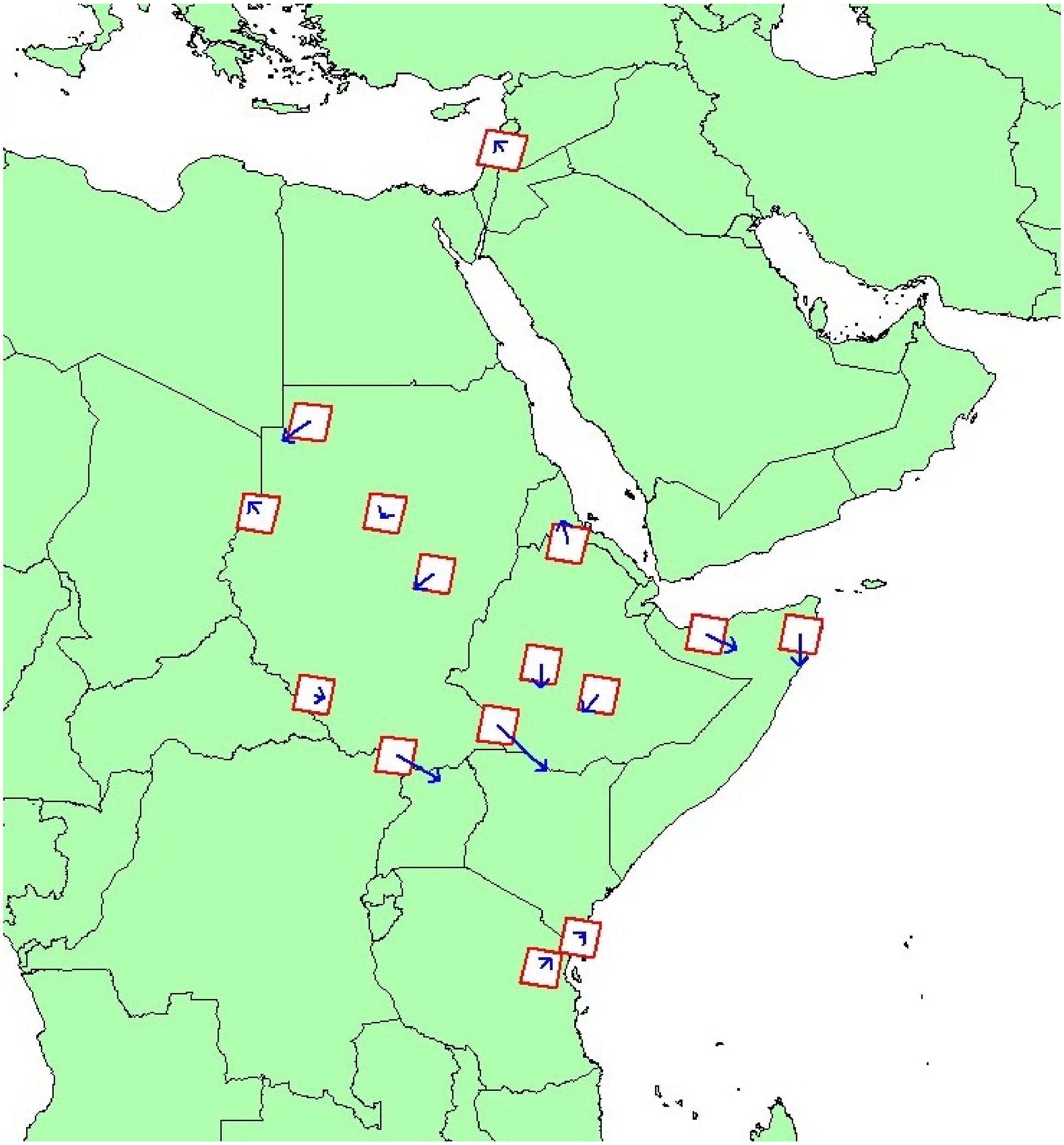
Central America Landsat TM Scene Errors



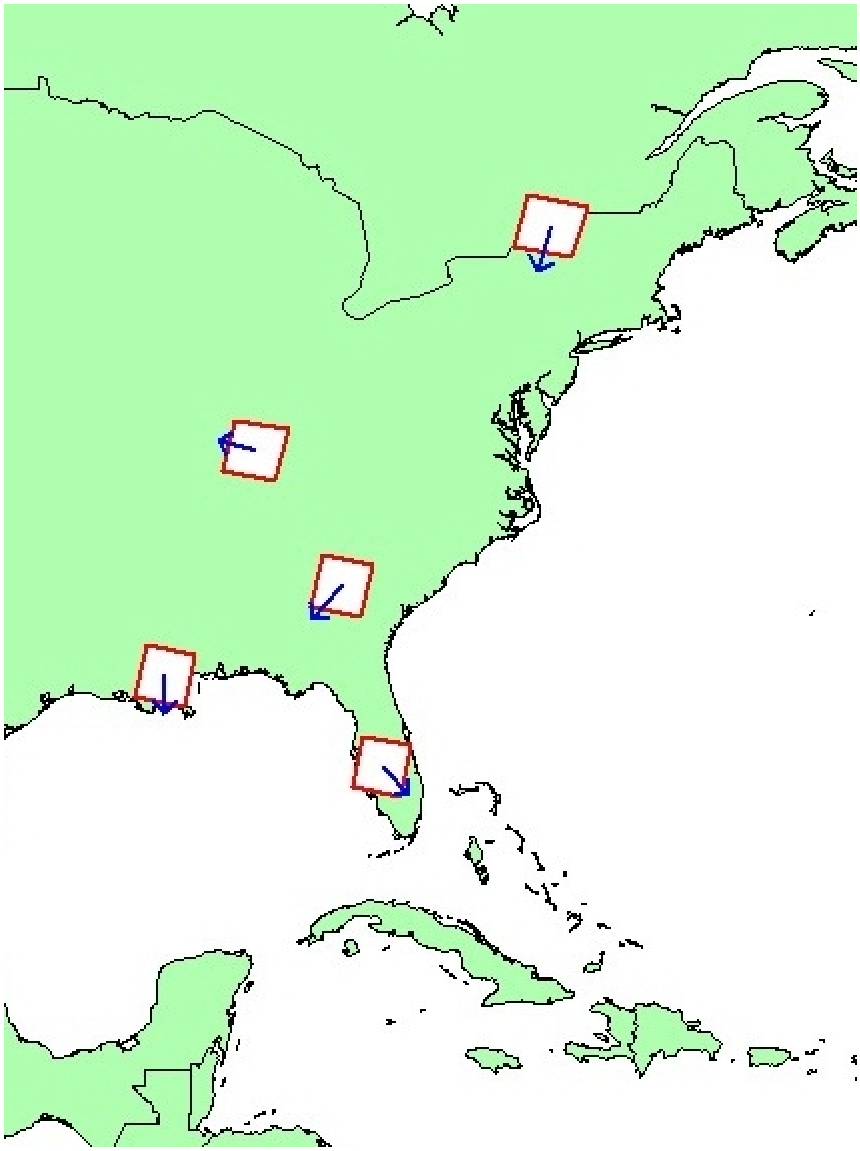
Central Asia Landsat TM Scene Errors



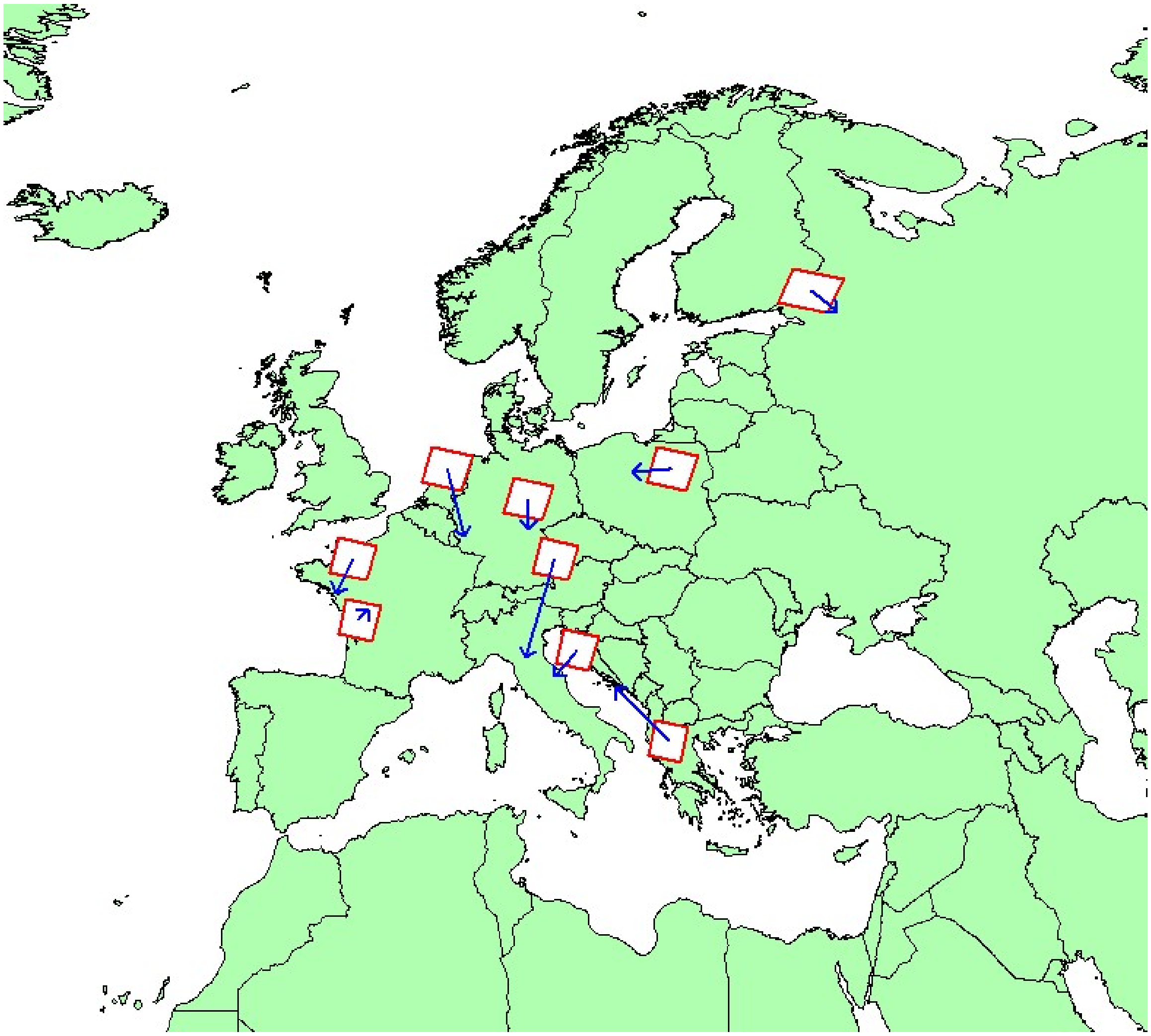
Central North America Landsat TM Scene Errors



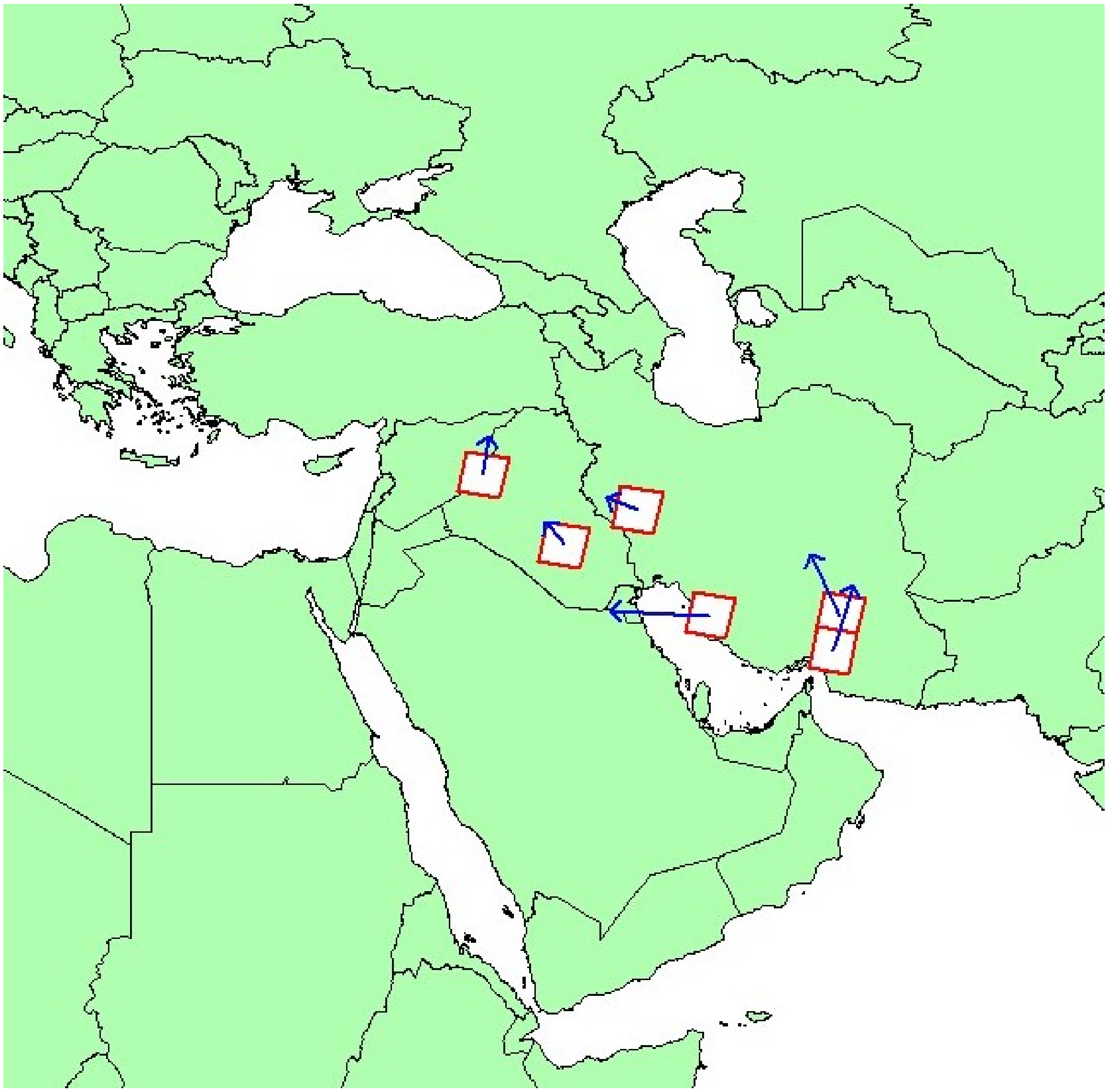
East Africa Landsat TM Scene Errors



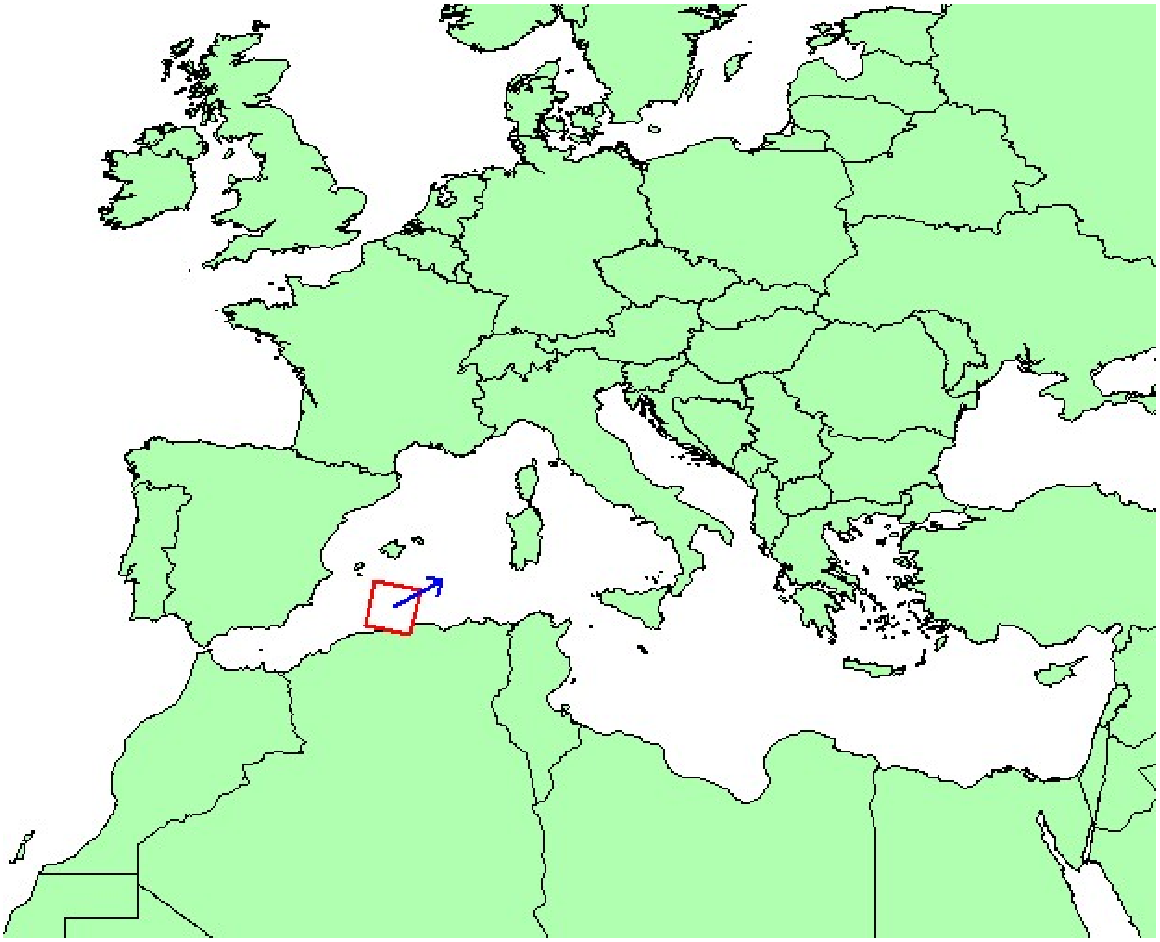
Eastern North America Landsat TM Scene Errors



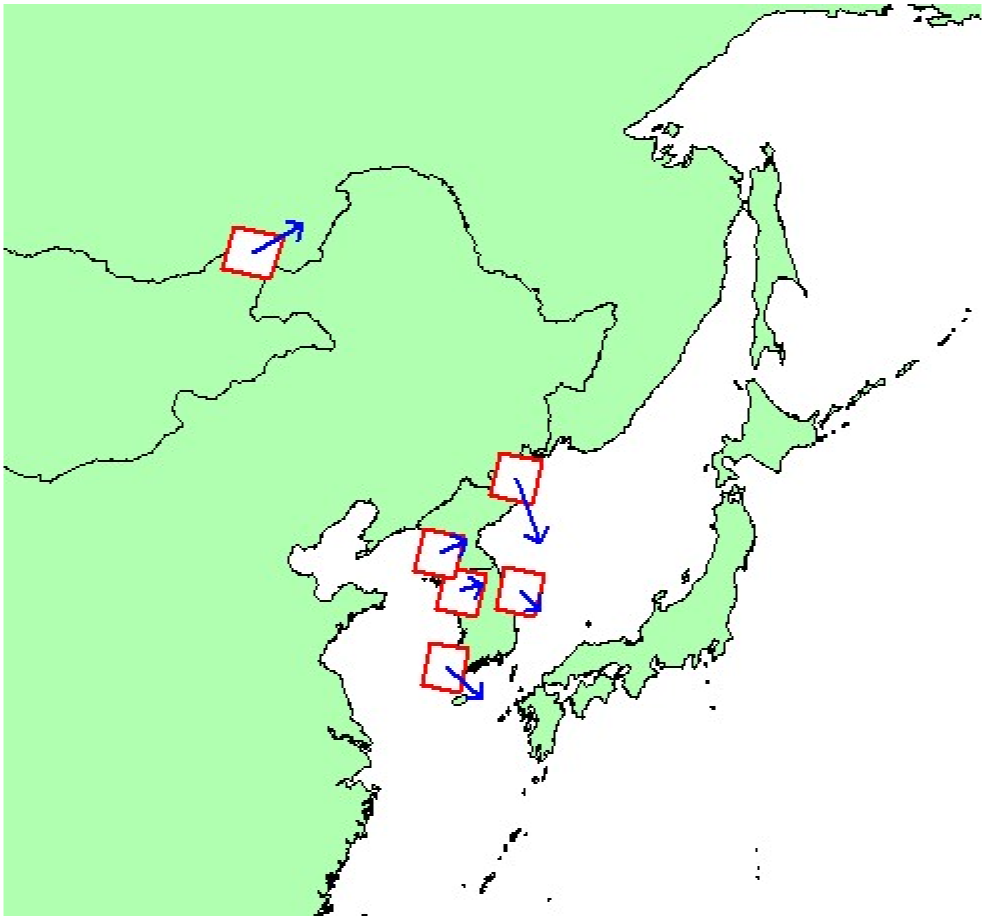
Europe Landsat TM Scene Errors



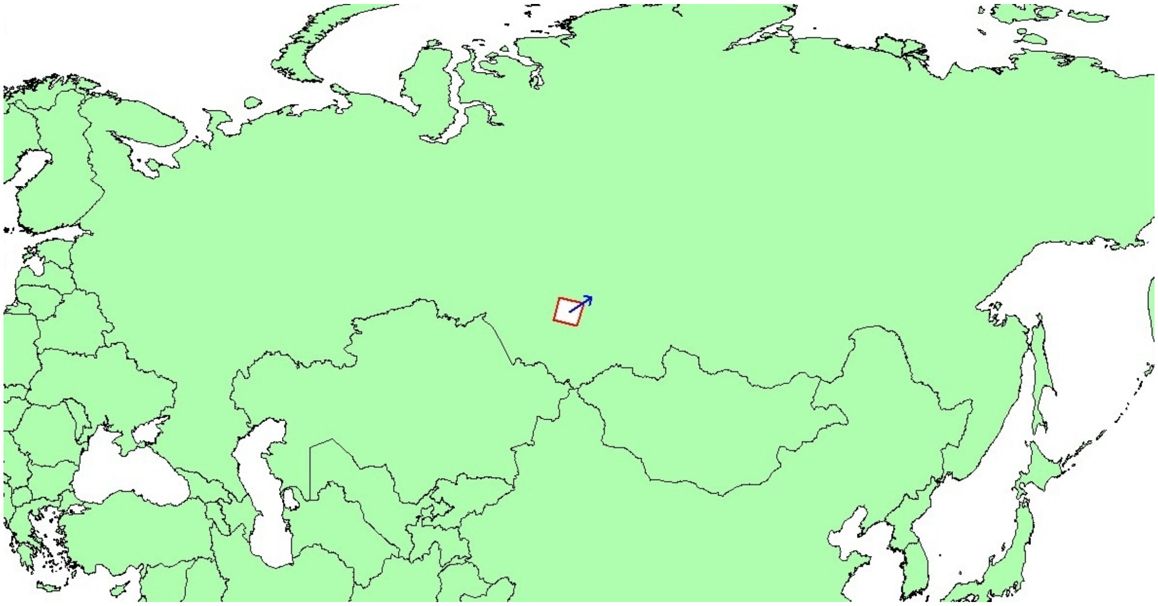
Middle East Landsat TM Scene Errors



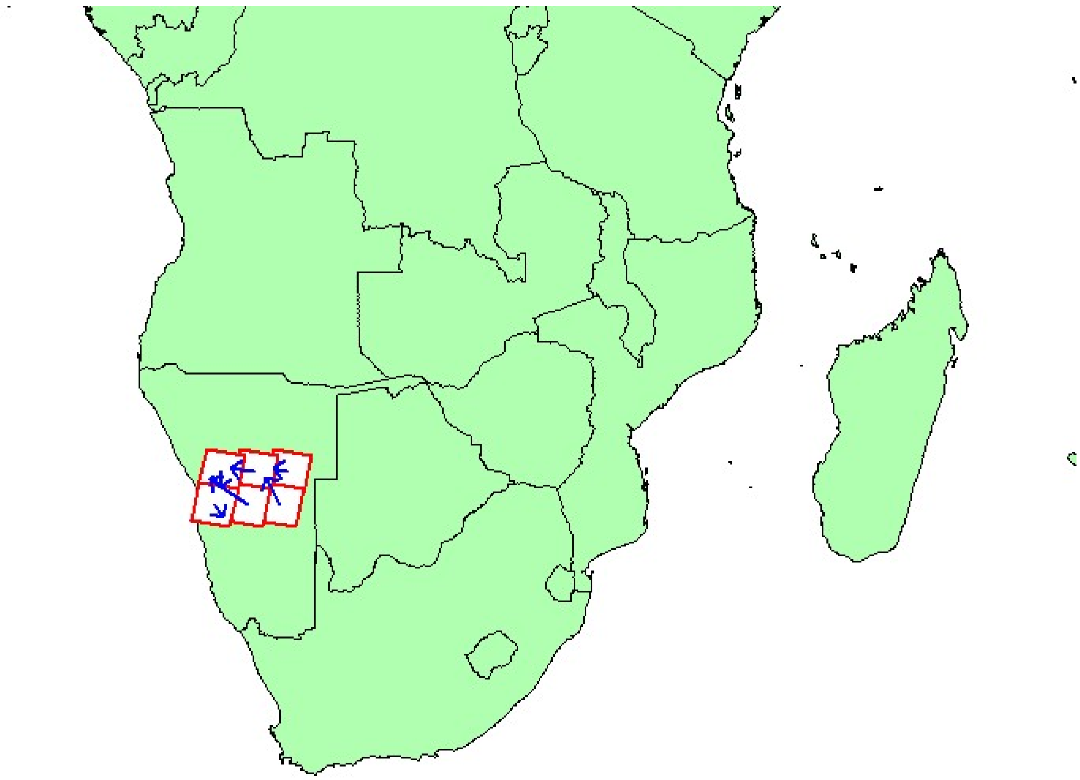
North Africa Landsat TM Scene Errors



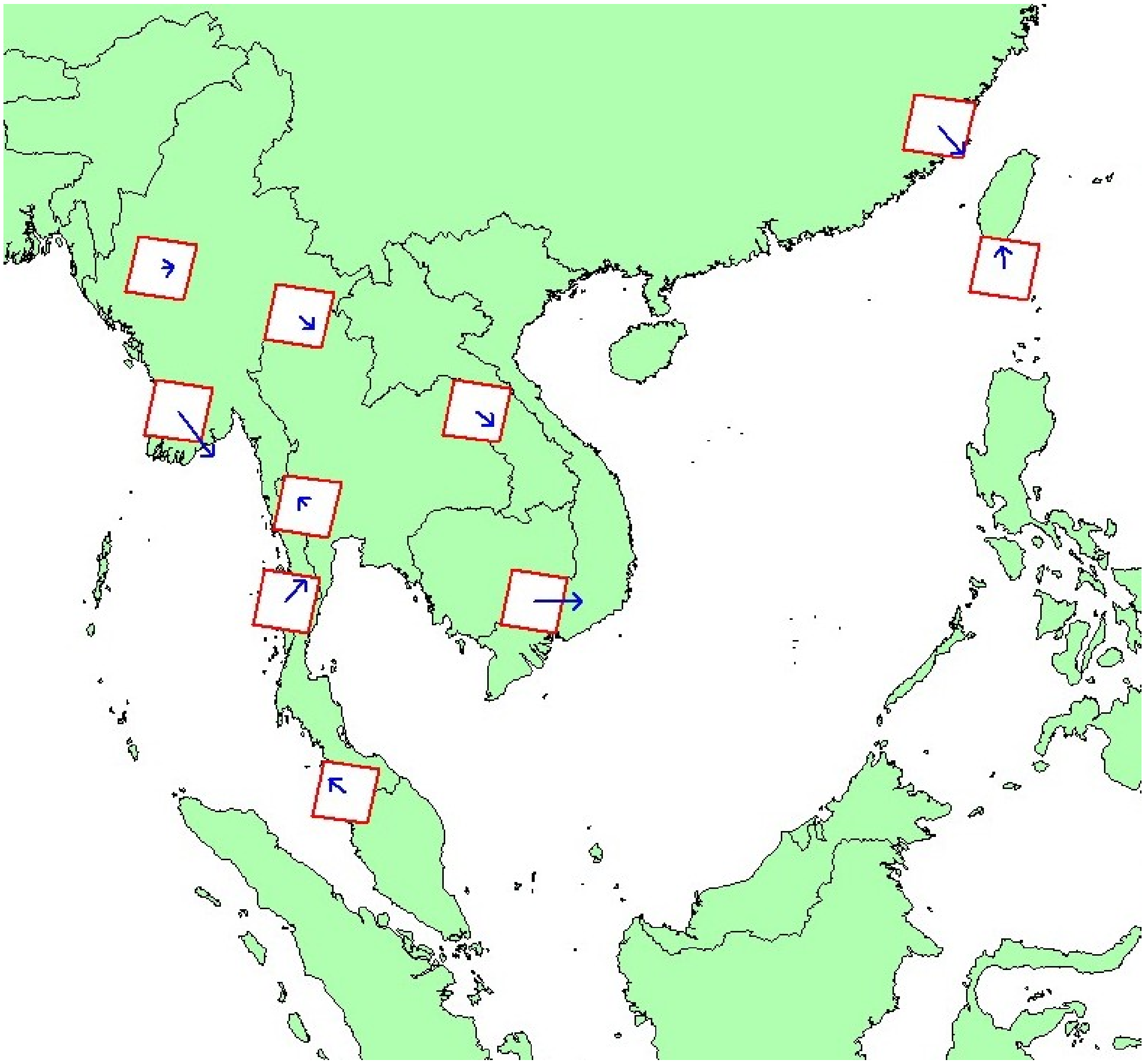
Northeast Asia Landsat TM Scene Errors



Northwest Asia Landsat TM Scene Errors

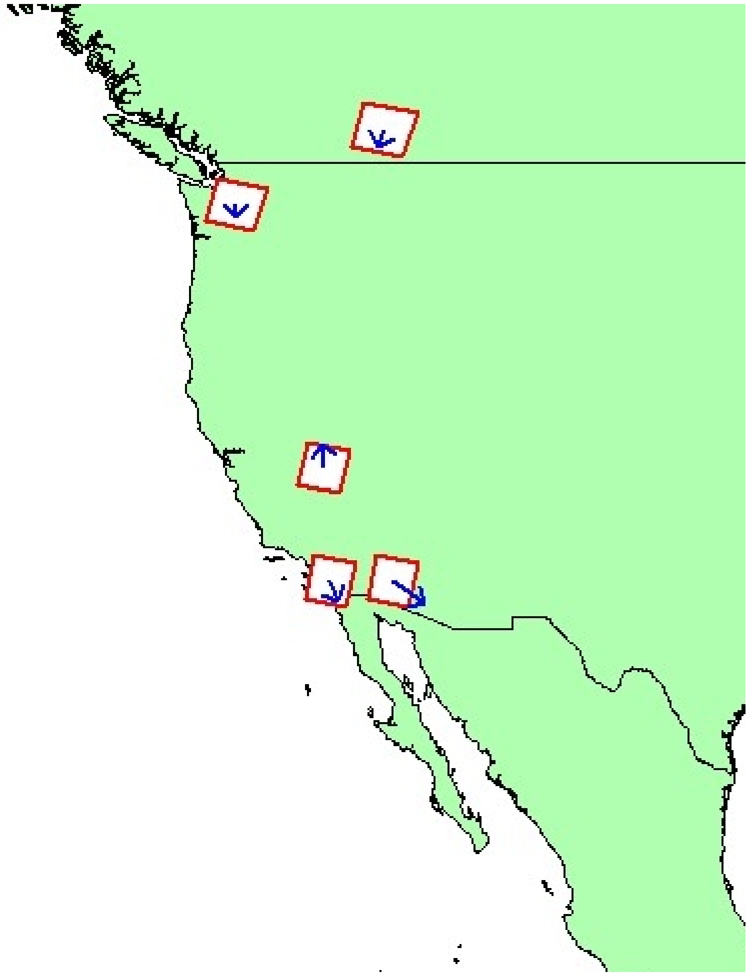


South Africa Landsat TM Scene Errors



Southeast Asia Landsat TM Scene Errors

Southern South America Landsat TM Scene Errors



Western North America Landsat TM Scene Errors

Appendix C

Landsat MSS Scene Accuracy Computations

Block	TM Path	TM Row	MSS Path	MSS Row	*RMSE$_x$* (m)	*RMSE$_y$* (m)	*RMSE$_{net}$* (m)
Alaska	65	15	71	15	27.70	26.83	38.57
Alaska	66	14	73	14	29.85	23.72	38.13
Alaska	66	16	73	16	18.61	18.78	26.43
~~Alaska~~	~~66~~	~~17~~	~~69~~	~~17~~	-	-	-
Alaska	67	18	73	18	14.66	25.59	29.49
Alaska	69	14	75	14	25.61	28.17	38.07
Alaska	69	16	75	16	28.44	25.69	38.32
Alaska	70	15	76	15	25.66	26.37	36.79
Alaska	72	17	78	17	30.86	22.68	38.30
Alaska	72	18	78	18	23.32	27.37	35.96
Balkans	165	22	178	22	32.41	22.80	39.63
Balkans	171	24	184	24	30.77	29.11	42.36
Balkans	179	20	193 / 194	20	28.26	28.96	40.46
Balkans	181	19	195	19	34.58	29.88	45.70
Balkans	183	19	198	19	27.78	37.07	46.32
~~Balkans~~	~~183~~	~~20~~	~~197~~	~~20~~	-	-	-
Caribbean	11	45	12	45	33.09	30.82	45.22
Caribbean	12	46	12	46	32.75	31.98	45.77
Caribbean	16	44	17	44	31.40	23.48	39.20
Central America	35	38	37/38	38	22.12	30.28	37.50
Central Asia	128	24	138	24	41.22	37.59	55.79
Central Asia	130	24	140	24	34.19	38.12	51.20
Central North America	24	39	26	39	35.24	31.16	47.04
Central North America	27	33	29	33	32.50	33.80	46.89
Central North America	32	36	34	36	30.99	29.65	42.89
Central North America	34	32	37	32	28.15	33.45	43.72
East Africa	161	53	173	53	28.81	31.30	42.54
East Africa	166	63	178	63	27.49	17.39	32.53
East Africa	167	55	179	55	29.64	25.13	38.86
East Africa	167	64	179	64	23.40	23.43	33.11
East Africa	169	50	182	50	28.94	27.23	39.74
East Africa	169	54	181	54	27.76	36.33	45.72
~~East Africa~~	~~170~~	~~56~~	~~182~~	~~56~~	-	-	-
East Africa	173	51	186	51	29.74	38.20	48.41
East Africa	173	57	186	57	34.42	43.14	55.19
East Africa	174	38	187	38	28.53	28.32	40.20
East Africa	175	49	188	49	31.46	39.23	50.29
East Africa	176	55	189	55	82.28	73.69	110.45
East Africa	178	46	191	46	51.43	51.55	72.82
East Africa	179	49	192	49	30.47	25.24	30.47

Block	TM Path	TM Row	MSS Path	MSS Row	$RMSE_x$ (m)	$RMSE_y$ (m)	$RMSE_{net}$ (m)
East Africa	165 (164)	53	177	53	21.39	26.16	33.80
Eastern North America	15	29	16	29	40.81	27.03	48.95
Eastern North America	16	41	17	41	48.54	45.29	66.39
Eastern North America	18	37	19	37	28.31	31.49	42.64
Eastern North America	21	34	23	34	22.70	23.65	32.77
Eastern North America	22	39	23	39	64.79	38.99	75.62
Europe	185	17	199	17	44.65	33.10	55.58
~~Europe~~	~~185~~	~~32~~	~~199~~	~~32~~	-	-	-
Europe	188	23	203	23	28.46	35.49	45.49
Europe	190	29	205	29	35.36	27.47	44.77
Europe	192	26	207	26	28.89	26.04	38.89
Europe	194	24	209	24	25.47	24.78	35.53
Europe	198	23	213	23	48.68	51.79	71.08
Europe	200	28	216	28	25.49	16.20	30.20
Europe	201	26	217	26	35.43	36.51	50.87
Middle East	159	40	171	40	29.14	37.72	47.66
Middle East	159	41	171	41	25.77	32.72	41.64
Middle East	163	40	175	40	29.72	40.81	50.49
Middle East	166	37	178	37	24.23	32.93	40.89
Middle East	168	38	181	38	26.86	26.06	37.42
Middle East	171	36	184	36	29.29	33.14	44.23
North Africa	196	34	211	34	31.52	52.10	60.89
Northeast Asia	114	34	123	34	25.17	32.85	41.38
Northeast Asia	115	31	124	31	36.64	30.75	47.84
Northeast Asia	116	34	125	34	27.84	25.46	37.72
Northeast Asia	116	36	125	36	25.20	24.80	35.36
Northeast Asia	117	33	126	33	24.87	26.91	36.64
Northeast Asia	126	25	136	25	33.90	28.56	44.33
Northwest Asia	146	22	157	22	32.62	30.57	44.71
South Africa	177	75	190	75	33.84	43.88	55.41
South Africa	177	76	190	76	29.75	27.09	40.27
South Africa	178	75	191	75	35.36	46.09	58.09
South Africa	178	76	191	76	47.03	33.86	47.03
South Africa	179	75	192	75	26.37	30.17	40.07
South Africa	179	76	192	76	23.92	28.66	37.33
Southeast Asia	117	45	126	44	40.90	35.75	54.33
Southeast Asia	119	42	127	42	26.99	32.48	42.23
Southeast Asia	125	52	134	52	26.88	24.79	36.56
Southeast Asia	127	48	136	48	32.95	33.20	46.78
Southeast Asia	128	56	137	56	22.49	25.78	34.21
Southeast Asia	130	50	140	50	81.98	27.38	86.43
Southeast Asia	130	52	139	52	82.00	22.97	85.15
Southeast Asia	131	46	140	46	27.29	24.07	36.39
B Southeast Asia	133	48	143	48	62.76	65.27	90.55

Block	TM Path	TM Row	MSS Path	MSS Row	$RMSE_x$ (m)	$RMSE_y$ (m)	$RMSE_{net}$ (m)
Southeast Asia	134	45	144	45	30.34	32.99	44.82
Southern South America	226	78	242	78	52.13	34.92	62.74
Western North America	38	37	41	37	38.49	24.70	45.73
Western North America	40	37	43	37	28.57	31.63	42.62
Western North America	41	34	44	34	23.74	30.61	38.74
Western North America	42	25	45	25	51.52	52.26	73.38
Western North America	46	27	50	27	27.17	36.72	45.68

Note: Rows highlighted in grey indicate that the imagery analysis was unable to be completed. Rows with red text indicate that the data failed to meet specification.